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Ground Warfare in 2050: How It Might Look

by Alexander Kott

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Office of the Director, ARL

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14. ABSTRACT

This Technical Note offers a brief technological forecast of selected military technologies and their employment in ground warfare in the year 2050. This document is a think piece presenting the author's opinions, intended for stimulating discussion and ongoing exploration of future directions in military technology. This Technical Note revisits ideas developed in the earlier US Army Research Laboratory report of 2015 *Visualizing the Tactical Ground Battlefield in the Year 2050*. It also elaborates on the context of several publications in which the author investigated possible features and capabilities of future autonomous intelligent agents and robots operating on the battlefield of the future.

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Contents

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I thank the fellow participants of the 2015 US Army Research Laboratory (ARL)/Army Research Office (ARO) workshop "Visualizing the Tactical Ground Battlefield in the Year 2050." Many points in this technical note revisit the discussions we held at that workshop.[1]

Similarly, I am grateful to the fellow members of the ARL Strategic Projections Committee, authors of Kott et al.,[2] some of whose ideas I incorporated into this document.

Dr Bryan Glaz, Chief Scientist (A) of ARL's Vehicle Technology Directorate, and Dr Adam Rawlett, Chief Scientist of ARL's Weapons and Materials Research Directorate, provided numerous valuable comments, corrections, and additions; I greatly appreciate their help.

I am also indebted to LTC David K Spencer, Chief of the Future Studies Branch at the Army Capabilities Integration Center. He helped me to elucidate the important areas I do not cover in this brief note, but which must not be overlooked in a broader future study.

Finally, thanks to Jessica Schultheis of ARL's Technical Publishing office who organized and edited my rough manuscript.

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[1] Kott A, Alberts D, Zalman A, Shakarian P, Maymi F, Wang C, and Qu G. Visualizing the tactical ground battlefield in the year 2050: workshop. Adelphi (MD); Army Research Laboratory (US); 2015. Report No.: ARL-SR-0327.
[2] Kott A, Choi K, Forch B, Franaszczuk P, Karna S, Lee S, Mait J, Reynolds P, Sadler B, Swami A, et al. Potential science and technology game changers for the ground warfare of 2050: selected projections made in 2017. Army Research Laboratory (US); 2018 Feb. Report No.: ARL-TR-8283.

1. Introduction

This Technical Note offers a brief technological forecast of selected military technologies and their hypothetical employment in ground warfare in the year 2050. This is a think piece intended for stimulating discussion and ongoing exploration of future directions in military technology.

In writing this document, I was motivated by several considerations and developments.

First, I felt it was time to revisit and perhaps reinforce ideas developed in the 2015 workshop "Visualizing the Tactical Ground Battlefield in the Year 2050" that resulted in the accompanying report ARL-SR-0327.[1]

Second, I wanted to elaborate on the context of several publications in which my coauthors and I have investigated possible features and capabilities of future autonomous intelligent agents and things operating on the battlefield of the future.[2–7] Similarly, this would provide a possible context for ongoing formulation and refinement of strategies for artificial intelligence (AI), both at the US Army Research Laboratory (ARL) and in broader Army Science and Technology communities.

Third, I see evidence that technological forecasting in the domain of warfare can be reasonably accurate. In an empirical study,[8] the accuracy of military technology forecasts, made by multiple authors in the 1990s with the specific horizon of 2020, had the impressive average accuracy ranging from 76% to 89%, depending on how one defines the accuracy. The long-term future of technology is not unknowable, and long-term forecasts of technology can be valuable contributors to informed decisions of defense Research and Development leaders.

Finally, this note is intended to contribute—as a part of a broader discussion—to the effort recently undertaken by the ARL Strategic Projection Committee to formulate a comprehensive document that depicts the technological environment of future ground warfare. This effort, in turn, is an extension of a narrower project executed in 2017–2018.[9]

2. Limitations and Disclaimers

This note presents the opinions of the author. It does not necessarily reflect positions or views of the author's employer, or of any other organizations, or of the author's colleagues.

This note is a think piece. Its intent is to provoke discussion, not to elicit an agreement. I believe that in long-term technological forecasting, vigorous polemics is more valuable than a comfortable consensus.

Furthermore, this think piece is not intended to offer arguments or recommendations for programmatic investments or priorities.

The scope of this discussion is limited to tactical ground warfighting circa 2050, in a major conflict between technologically advanced peer competitors.

I do not assume that the United States is a participant in this conflict. Nothing here is specifically about the United States. The combatants of both sides depicted in this document could be any technologically advanced powers of 2050. To stress this point, and to avoid associations with any of today's powers, I call the opposing parties the Beige and the Lilac. For the sake of concreteness, I use the Beige as the protagonist.

To keep the scope of this discussion manageable, I do not touch (or touch extremely lightly) on many relevant topics, including the following, among others: any current programs, requirements, policy, budget, sociocultural and geopolitical issues, weapons of mass destruction, inherently naval or airspace issues, space or maritime assets or operations, biological technologies, human augmentation, etc.

To further limit the scope of this technical note, I do not cover air–land combined operation or airspace deconfliction. This could be justified if we restrict the discussion to a phase of ground operations when Beige air assets are constrained by the Lilac's air defenses. Likewise, in the interest of scope, I do not discuss direct-fire engagements. Furthermore, I barely touch on many informational aspects of the future warfare, ranging from intricacies of links between "seeing" and "shooting" to immense depth of information and cyber-electromagnetic activities (CEMA).

The glimpses of the future hypothesized here are merely a few selected narrow windows onto a much larger landscape of the future warfare. They are not exhaustive in any way. This Technical Note is truly a note—my jotting down a few threads of thought.

It is understood that while many things change in warfare, many others change little. Much of the technologies, systems, and tactics of 2050 will be familiar to a military practitioner of today. This note tries to focus on those other elements that are more likely to differ from today's, while avoiding unrestricted "imagineering".

To constrain my flights of imagination and technological enthusiasm, I tried to follow these three guidelines:

1) A forecasted technology should not contradict the currently known **trends**, either recent or long-term, unless strong reasons exist for the trend to change.

2) A forecasted technology should be driven by a strong **necessity** to counteract a capability of the opponent.

3) A forecasted technology should have science and technology **precursors** that suggest its feasibility, at least in the long term.

These guidelines tend to engender more conservative forecasts, which I accept for the purposes of this document. To be sure, the history of military technology does present important examples that violate the three guidelines listed above. However, they are relatively uncommon (see Kott and Perconti[8] and Handel[10]).

I now proceed to discuss the technologies that could support such operations in 2050. I have organized the discussion into four sections, covering the traditional categories: Move, Shoot, Protect, and Communicate.

3. Move

While most ground vehicles will continue to use the proven wheeled and tracked locomotion, a growing fraction of vehicles, especially the ground robots intended for operations in highly cluttered, broken terrain such as urban rubble and forests, will use legged locomotion. The advances of legged locomotion in the last decade have been remarkable[11] and are likely to continue so; by 2050 it will be a fully proven, robust technology.

Similarly, a growing fraction of ground robots will be equipped with limbs for climbing over (pulling themselves over) boulders, piles of fallen trees, urban rubble, and such.[11,12] Advances in combining such capabilities to interact with the world much as humans do with the legged mobility advantages mentioned previously, along with the AI paradigms to efficiently control these behaviors, are likely to be made in parallel. The confluence of these capabilities will enable the robotics/autonomous mobile platforms required to compete with a near-peer adversary of the future in hybrid rural/urban environments.

Aerial platforms, both robotic and manned, will rely primarily on various forms of tilt-rotor technology, which is currently at its relatively early stages of full acceptance, and will be a mature technology in 2050. Nap-of-the-earth (NOE) flight, very close to the ground, will be widely used to minimize detection and targeting by the adversary, and because autonomous AI pilots will become more effective in such flight than humans.[13] Furthermore, autonomy will be critical to enabling vertical lift platforms such as tilt-rotors that will need to be in a state of near continuous operational availability over multiple days in order to survive near-peer long-range precision fire capabilities.

Some light vehicles, even manned, will fight on the ground but will have the ability to be transported via air. Each vehicle will be assigned a helicopter robot that would arrive to the ground vehicle and rigidly couple with it for the duration of the NOE flight. This concept was originally proposed as a part of the Army After Next study in 1990s,[14] and will be even more relevant in 2050 when most vehicles are unmanned, and highly effective robotic helicopters are available. Supplies will be ferried around the battlefield in a similar fashion.

The relentless advances in battery technology[15–17] suggest that by 2050 most vehicles will be electric and battery-powered. To charge the batteries, the Beige force will be equipped with specialized robotic vehicles that will serve as mobile power generation plants[18] and traveling charging stations. Even during an active engagement, they will shuttle between the combat vehicles, autonomously recharging them as needed. The traveling charging station might also use lasers to charge aerial robots while they are in flight.[19]

These power-generating vehicles may use conventional power plants with multifuel capability, or perhaps future alternatives such as isomer-based power generation.[20] In this way, the fire platforms enhance their primary combat functions and reduce heat/noise signature by discarding the burden of carrying a built-in power generator. This may also help the combat vehicles employ directed energy weapons.[21]

Even with NOE flights and effective use of ground clutter, the future battlefield—saturated with sensors and indirect precision fires—can be so lethal that in more static operations the only way to move will be through underground tunnels. Tunnel digging robotic machines—motorized for battlefield mobility—will find growing use for supporting subterranean mobility.[22,23]

Depending on the mission, some light Beige units will move in a manner that minimizes the probability of their detection by the Lilac intelligence, surveillance, and reconnaissance (ISR). Such units will make the use of camouflage, cover, and concealment. While moving, often through urban clutter or dense vegetation, they will use ground robots that are likely to be of a modest size (say, comparable to a mule or a bear), with dexterous legged locomotion. They will be used mainly to transport and emplace lightweight fire assets, recharging stations, and communication nodes, although they will be able to carry perhaps one or two Soldiers when necessary. However, to minimize the probability of detection, the humans will commonly travel on foot, sometimes assisted by exoskeletons and other forms of wearable robotics,[24,25] and communicating with robots via brain-to-AI interfaces.[6,26,27]

4. Shoot

Missiles, loitering munitions, and artillery rounds—which are increasingly acquiring guidance fins, seekers, and rocket and ramjet boosters—are gradually converging, and by 2050 will form a continuous spectrum. For the purposes of this document, I refer to all missiles, shells, projectiles, and even loitering munitions simply as missiles.

Some missiles will become high supersonic, although subsonic and slow-loitering or hovering (and even perching) aerial devices will also find broad use. Further, most missiles will be capable of flying NOE and aggressively maneuvering to defeat their target in spite of countermeasures. This will include the ability to maneuver into and within entrenchments and other fortifications. Missiles will be hardened, to increase survivability against countermeasures, both kinetic and CEMA.

A large fraction of missiles of both Beige and Lilac will be intelligent and autonomous.[28] Their degree of autonomy will be subject to the policies that the Beige and/or the Lilac may or may not have regarding the human control of autonomous weapons. (I remind the reader that neither Beige nor Lilac are necessarily representing the United States.) Such missiles will be able to perceive and assess the targets (potentially multiple) and the surrounding environment; form an effective plan of attack that depends on specific conditions of defenses and countermeasures of the target; identify the best attack points on the target, approaches, etc., and collaborate with other missiles to defeat the target's protection.

It is possible that Beige and Lilac will use explosives and propellant with 3–10 times greater energy density than those available in 2018. For example, progress is being made[29] toward synthesizing a polymeric form of nitrogen molecules predicted to contain large chemical energies three times that of the most powerful explosives used today.

Typically, the intelligent missiles will be carried on ground platforms. The Beige's ground platforms will execute their fires and maneuvers in widely dispersed but coordinated formations. Some fire platforms will be manned; many others will be unmanned, maneuvering autonomously, and executing fires on command received from the human personnel in manned vehicles or from remote locations.[6]

The ground fire platforms will also be capable of direct fire, although the role of direct fire will diminish by 2050. Direct fire engagements will see growing use of directed energy weapons against softer targets.[21] This will be facilitated by the availability of specialized power-plant vehicles mentioned in the Section 3 ("Move").

In addition, both Lilac and Beige will use missiles to deliver intelligent mines and ground sensors within the area of operations or avenues of approach of the opponent. Once emplaced, Lilac's intelligent mine will observe the approaching Beige force and attack the Beige assets via either an explosive charge or by firing a missile (compare with the M-7 Spider [30]).

A fraction of the Beige fire platforms will be dedicated to delivering CEMA effects[2] at Lilac's assets and incoming missiles.[31] In particular, the Beige will deliver CEMA effects via its own missiles that approach the Lilac assets, loiter or perch in the vicinity, and seek a suitable opportunity to deploy wirelessly a malware agent on a Lilac's asset, or to manipulate the Lilac's communications or sensing. In general, CEMA effects will be short-lived because the Lilac assets will have onboard autonomous counter-cyber capabilities.[4,5] Therefore, Beige assets will coordinate (probably on a peer-to-peer basis) CEMA attacks with kinetic attacks to achieve lasting physical effects during the short window of opportunity when the CEMA effect is active.

Unlike the mounted platform-heavy units that rely on armor and antimissiles for protection, the light Beige units will survive by using cover and concealment in urban clutter and dense vegetation. To execute their fires, the light Beige force will use a load of light, intelligent missiles along with light unattended launchers. These will have the advantage of reduced signatures and limited susceptibility to counter-battery fires by Lilac. The missiles will be prepositioned, by the organic ground robots of the light force (see Section 3, "Move"), and left unattended in appropriate locations with remotely controlled launchers. Once fired, the intelligent missiles will approach the target in a way that minimizes the probability of premature detection and will cooperate at the target to produce the most appropriate effect in spite of local antimissiles. Multiple targets would be attacked in rapid succession to preempt the Lilac counter-battery fires.

5. Protect

In a sensors-saturated environment of 2050,[1] the Beige force that is capable of producing strong lethal effects—substantial in size and mounted on vehicles—will be unlikely to avoid detection, observation, and fires by the Lilac; therefore, the

Beige mitigates the Lilac fires primarily by what I call antimissiles, and secondarily by armor.

Granted, to enhance its survivability, the Beige will take measures to minimize its observability: the Beige force will maneuver and disperse, using quantities of diverse decoys,[12,32] and vigorously attack the Lilac ISR assets.[33] Nevertheless, the probability of the Beige force being detected is high, and it will likely receive continuous indirect precision fires from the Lilac.

To protect itself against the Lilac's indirect precision fires, the Beige will have to rely primarily on extensive use of intelligent antimissiles (evolutions of today's Active Protection Systems [APSs], Counter Rocket, Artillery, and Mortar [C-RAM], Iron Dome, etc.), and less on armor. I remind the reader that I use the term "missile" very broadly (see Section 4, "Shoot"). Thus, "antimissile" also includes a diverse range of systems, generally with a degree of intelligence and autonomy,[28] which are able to detect, attack, and defeat incoming Lilac missiles.

Unlike today's APSs, the fire platforms will carry few, if any, antimissiles. Instead, specialized autonomous protection vehicles will surround the fire platforms and use their extensive load of antimissiles to defeat the incoming Lilac missiles. An analogy might be a carrier strike group (the primary effect producer, the carrier, surrounded by a protective shield of other vessels), or a formation of bombers surrounded by fighters in the World War 2 Allied air raids.

The antimissiles will be carried not only by ground protection platforms but also by a cloud of aerial robots loitering or hovering around the battlefield. Some of these too will fire antimissiles, or otherwise intercept the incoming missiles, in some cases more effectively than a ground-launched antimissile.

Armor will not disappear but will change its role as it will become relatively ineffective against multiple collaborative intelligent missiles. Use of heavy armor, comparable to the one commonly used in 2010, will be less common. On the other hand, relatively light armor will continue to protect against fragmentation threats and from debris of missiles destroyed by antimissiles.

Extensive use of a variety of decoys and false targets—both physical and electromagnetic—will be an important way in which the Beige force will diminish the effectiveness of Lilac fires.[21] Also much broader will be the use of obscurants and other methods to reduce the Beige force's visibility to Lilac's ISR and incoming missiles.

In addition, a counter-reconnaissance fight will be highly important and will be to a large extent a robot-on-robot affair. The Beige aerial robots and ground robots of various sizes, including micro-robots, will be patrolling the space around the Beige force, trying to locate and destroy the Lilac's hard-to-see aerial robots and ground robots that observe the Beige. Similarly, when the Lilac employs intelligent mines in the vicinity of Beige, the Beige platforms will disembark marsupial small ground robots and aerial robots that will seek and destroy the Lilac mines that threaten the Beige platforms.

Protection against CEMA effects will receive high priority. The cloud of aerial robots surrounding the Beige force will include a fraction of dedicated aerial robots specializing in counter-CEMA actions. Each Beige platform, and Beige missiles, will be equipped with a collection of autonomous CEMA defense agents that continually seek and defeat CEMA threats that intrude into or impact the platform.

The light dismounted Beige forces will have limited, if any, protection either from antimissiles or armor (although they may be provided a degree of protection by armor deployed by their robotic helpers [compare Baechle et al.[34]]). Instead, they will use cluttered ground terrain to obtain cover and concealment. In addition, they will attempt to distract and deceive the Lilac by use of decoys.[21]

Beige will find it particularly difficult to protect its large static assets such as supply dumps or munitions repair and manufacturing shops. Conventional entrenchments and other fortifications will become less effective when teams of intelligent munitions can maneuver into and within a trench or a bunker. Extended subterranean tunnels and facilities—often created by teams of Beige mobile boring machines—will become especially important.

6. See, Think, Communicate

Both Beige and Lilac will strive to gain maximum information regarding each other's locations, strengths, and activities. ISR will be collected primarily via multiple unmanned assets,[28] both ground robots and aerial robots, many of them of small and micro size, difficult to detect, and capable of approaching closely the adversary assets. Because micro-robots will find it difficult to traverse long distances, they will likely be delivered and deployed in the vicinity of the adversary by larger missiles (compare Weisberger[35]). Intelligent missiles (discussed mainly in Section 4, "Shoot") will also carry sophisticated sensors and processing capabilities, and will contribute information to the overall ISR collection.

ISR robots will be capable of an autonomous path and collection plan based on a specified broad intent of the mission; fast NOE movements through forest and urban terrain; self-managing of trips to charging/refueling stations, self-recharging; collaborative planning and operations; and adversarial reasoning to minimize probability of detection. They will be optimized for low-signature, energy-efficient operations to reduce the probability of being detected (and destroyed) by the Lilac counter-ISR assets,[33] and to prolong the period of operations without recharging. The ISR robots are likely to be equipped with sensors capable of high-resolution, 3-D imaging in the visible and IR bands over a large field of view, delivering a far greater level of detail than was possible in 2018.[9]

Most ISR assets will have to be capable of sharing their information both in a peer-to-peer basis and with the command and control (C2) system. Because unconstrained sharing can be counterproductive, it will be guided by the C2 system as well as by the asset's onboard assessments of who needs to know what.

Because of the high volume and diversity of the information collected by the Beige ISR robots, and because a high fraction of the Beige force will be robots that require detailed and unambiguous command, the C2 system will be highly automated and capable of autonomous execution of the bulk of C2 functions.[36] Further, because the Beige force—and the human participants of the force—will be widely dispersed (to minimize observation by the Lilac ISR, and destruction by Lilac fires), the C2 system will be widely distributed over multiple nodes,[32] with a significant degree of redundancy in order to tolerate partial attrition.

The C2 system will be capable, in mostly autonomous mode but with human guidance, if available,[27] of interpretation and fusion[37] of large volumes of information of diverse types and abstraction levels[38]; recognition of targets and activities from several dissimilar types of information; reduced susceptibility to deception and concealment; recognition and interpretation of enemy and friendly activities (including deceptions) on a broad battlefield scale; and projection of adversary upcoming activities (continuous estimates of enemy situation).[39–41]

The near-autonomous C2 system will also be capable of preparing courses of action and plans (including deception plans[42,43]) for robotic collectors, movers, and fire assets; continuous monitoring and dynamic management of a robotic battle at scale with limited guidance from humans[6]; and issuing commands to mostly robotic forces.

Beige communications will be characterized by careful attention to low probability of detection, because detection by Lilac will bring fires on the detected node. To minimize the probability of detection by Lilac electronic warfare, Beige is likely to use directional transmissions, low-power and short-range transmissions, and form a multi-hop network with multiple small ground robots and aerial robots serving as relays.[3] To minimize the chances that Lilac would jam the communications, the Beige network will use multiple diverse channels of different types.[44]

The networks will be managed by intelligent network management agents that will collaboratively monitor the state and activities of and on the network; perform automatic configuration changes when an agent detects network anomalies; handle decentralized trust management; self-form and self-heal the networks in response to adversarial disruptions; and anticipate and proactively adapt to adversarial actions.[3]

Cyber defense of the Beige network will be performed primarily by autonomous intelligent cyber defense agents[4,5] capable of continuously monitoring the networks and hosts; detecting and assessing the Lilac malware actions on Beige assets and of other hostile cyber activities; planning and executing complex multistep activities for defeating/degrading sophisticated Lilac malware; deceiving Lilac malware; anticipating and minimizing side effects on Beige assets; conducting adversarial reasoning to avoid detection and defeat by Lilac cyber agents; and collaboratively planning with other Beige agents.

7. Conclusions

Subject to all the limitations and caveats I discussed earlier, several notable themes can be discerned in the battlefield picture painted in this document. It is important to note that two primary trends are already well underway, and all other forecasted developments are largely derived from these two existing trends.

The existing trend toward the growing use of small aerial robotic devices for ISR will continue, creating an environment where hiding will be difficult, and distance from the opposing forces will not protect one from being observed.

This in turn will necessitate the extensive use of a variety of decoys (themselves based on intelligent robotic devices); the counter-reconnaissance fight will grow in importance and will have to be mainly a robot-on-robot affair.

The second existing trend that will continue strongly is the proliferation of intelligent munitions. These will be capable, in collaborative teams, of defeating armor, negotiating long distances, and maneuvering into and within entrenchments, seeking and defeating their designated target assets.

This potent threat will necessitate the growing use of unmanned assets, with humans becoming a minority within the overall force, and further dispersing over the battlefield (a long-term historical trend).

Furthermore, the threat of the intelligent munitions will have to be mitigated primarily by missiles and only secondarily by armor and entrenchments.

Specialized autonomous protection vehicles will be required that will use their extensive load of antimissiles to defeat the incoming intelligent munitions.

Seeking greater opportunities for cover and concealment, a force will increasingly gravitate to very complex terrain, such as dense forest and urban environments. This in turn will necessitate the development of ground robots with legs and limbs.

As the force becomes dominated by robots—typically electric and battery-powered—the force will also have to acquire a significant number of specialized robotic vehicles that will serve as mobile power generation plants and charging stations.

To gain protection from intelligent munitions, extended subterranean tunnels and facilities will become important. This in turn will necessitate the tunnel-digging robotic machines, suitably equipped for battlefield mobility.

The enormous quantity of computing and communicating devices on the battlefield will be a medium where a pervasive CEMA fight will unfold. This will have to be fought largely by various autonomous cyber agents that will attack, defend, and manage the overall network of exceptional complexity and dynamics.

Because of the high volume and velocity of information produced and demanded by the robot-intensive force, the C2 system will have to be capable of autonomous execution of the bulk of C2 functions with only a moderate degree of supervision by humans.

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List of Symbols, Abbreviations, and Acronyms

3-D	three-dimensional
AI	artificial intelligence
APS	Active Protection System
ARL	US Army Research Laboratory
ARO	Army Research Office
C2	command and control
CEMA	cyber-electromagnetic activities
C-RAM	Counter Rocket, Artillery, and Mortar
IR	infrared
ISR	intelligence, surveillance, and reconnaissance
NOE	nap-of-the-earth

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